Single Wake Meandering, Advection and Expansion - An analysis using an adapted Pulsed Lidar and CFD LES-ACL simulations

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Single Wake Meandering, Advection and Expansion
An analysis using a pulsed lidar and CFD LES-ACL simulations

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1- Project outline

Goals:

- Study of the single wake dynamics
  - **Meandering**: wake motions governed by large scale turbulent structure in the atmosphere
  - **Advection**: speed of the wake downstream transportation
  - **Expansion**: increase in radial extend of the wake deficit caused by small scale turbulent diffusion, pressure recovery and meandering

Methods:

- Experimental and numerical study
  - Measured wake meandering against model predictions (DWM)
  - Measured expansion against EllipSys3D simulations and other engineering models
  - Calibrate the advection velocity of the DWM model

2 – Experimental approach: set up

- June 2011 to January 2012, intermittent, DTU Risø Campus

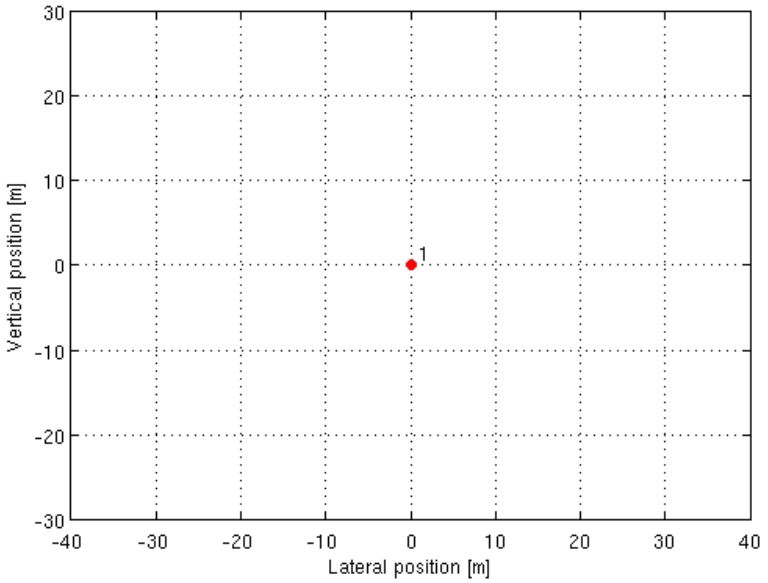
- WindCube pulsed lidar WLS7, developed and adapted at SWE

- 5 simultaneous cross section scanning at ≈ 1D, 2D, 3D, 4D and 5D

- Cartesian pattern of 7X7 points

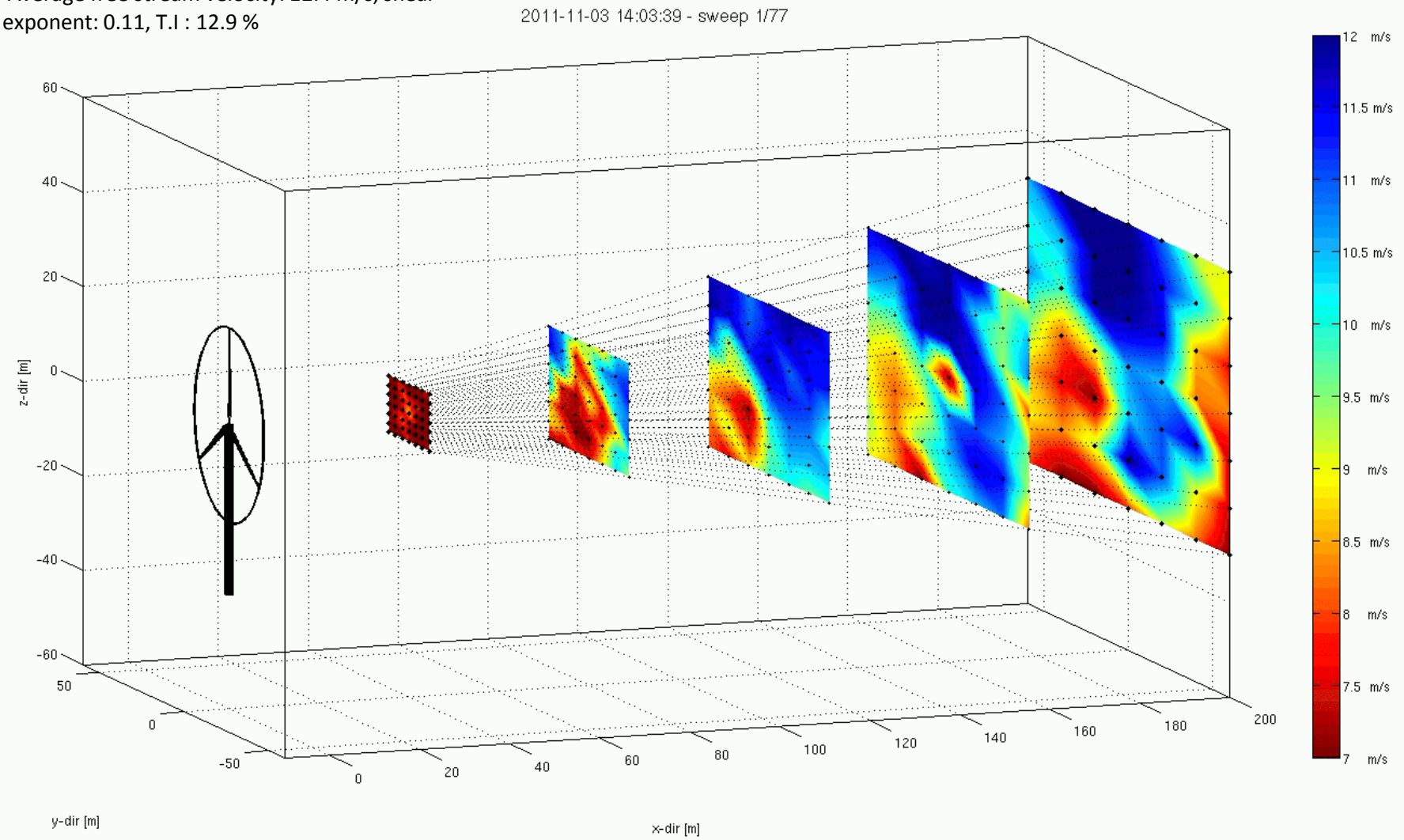
- 2 half-opening angle tested: 8.5deg and 16.7deg

- Sweep time ≈ 7.8 sec



2 – Experimental approach: wake resolving

Unfiltered line-of-sight velocities,
Average free stream velocity: 12.4 m/s, shear exponent: 0.11, T.I : 12.9 %



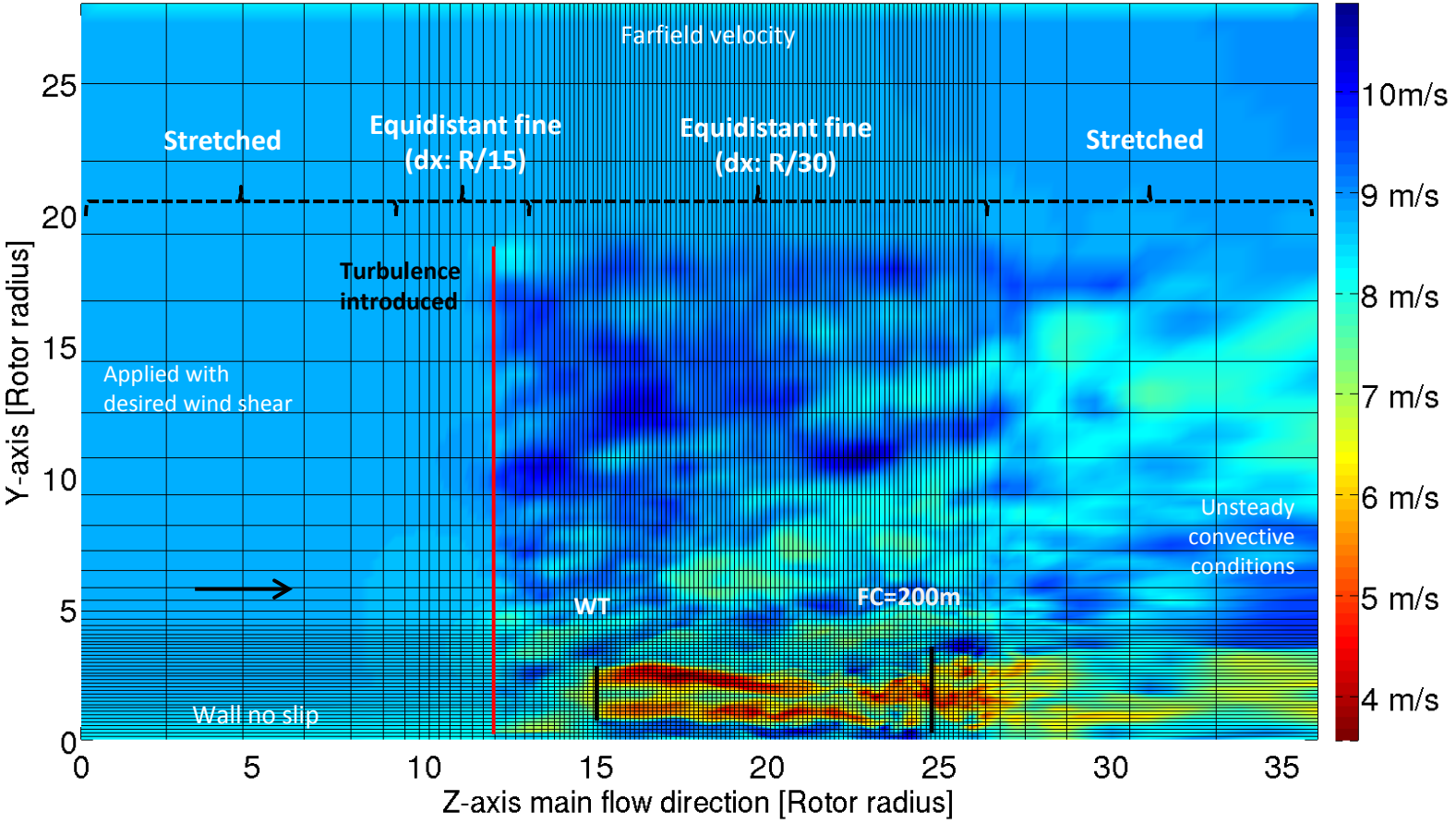
- Wake resolving similar to previous study using Continuous Wave Lidar at Tjaereborg

3 – Numerical approach: set up

Key features:

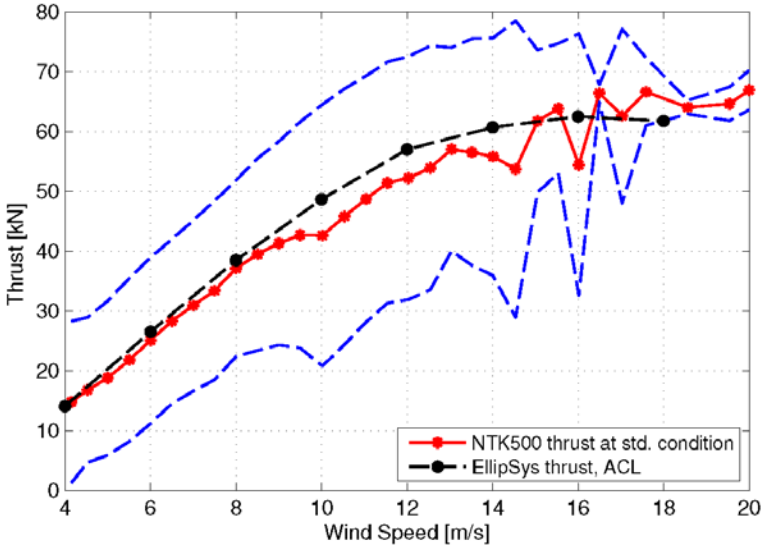
- **EllipSys3D** flow solver ; **Actuator Line Technique ; Large Eddy Simulation** , Constant RPM, constant pitch, no yaw
- **ABL** modeled:
  - **shear**: applied at the inlet using a power law
  - **synthetic turbulent** fluctuations, **Mann model** applied in a single cross section close to the inlet
- Unsteady computations: 10 minutes flow field statistic

17.92M cells

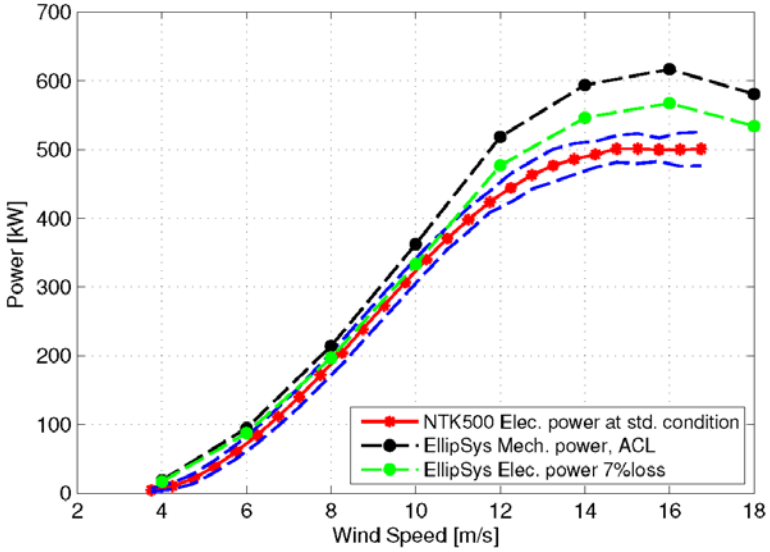


3 – Numerical approach: validation

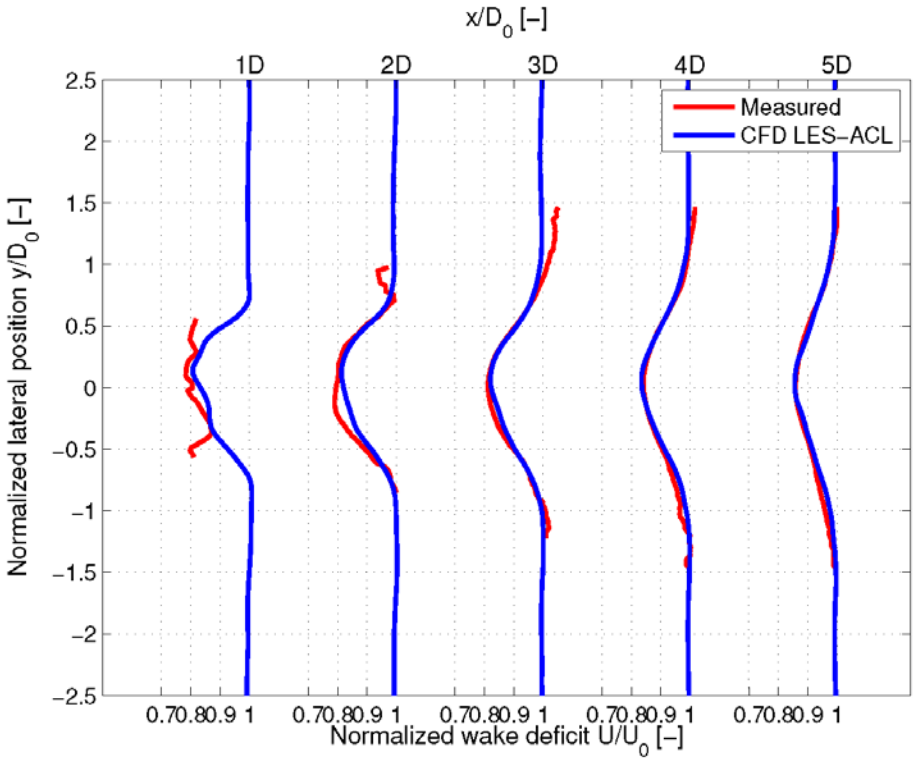
Thrust curve



Power curve



Normalized wake deficit in meandering frame of reference



4 – Measured wake meandering

- Mean shear contribution removed

↓

- Tracking procedure for each lidar sweep

↓

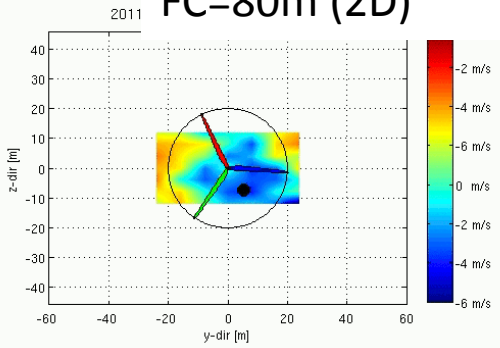
→Optimization: bivariate Gaussian shape fitting through least-squares approach

$$f = \frac{A}{2\pi\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{(y_i-\mu_y)^2}{\sigma_y^2}+\frac{(z_i-\mu_z)^2}{\sigma_z^2}\right)\right]$$

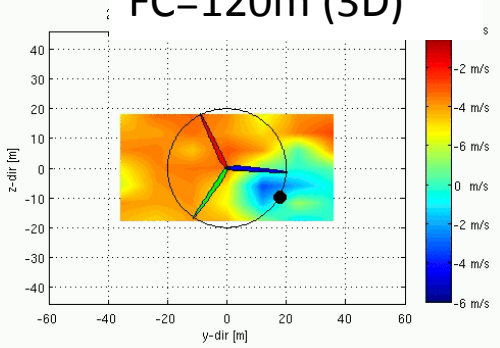
↓

- Discrete to continuous meandering paths for wake center

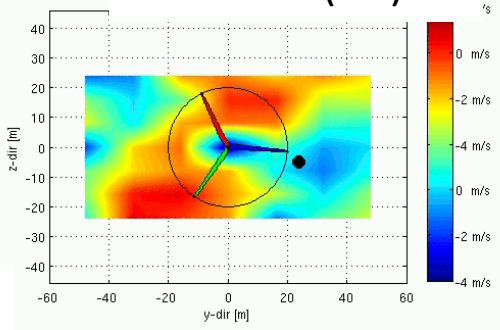
FC=80m (2D)



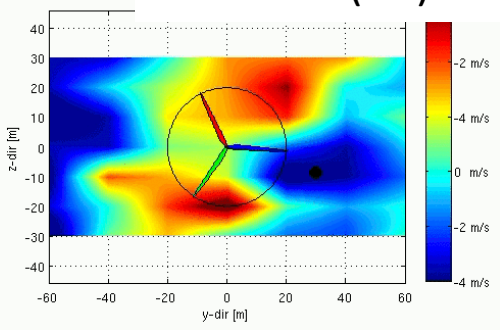
FC=120m (3D)

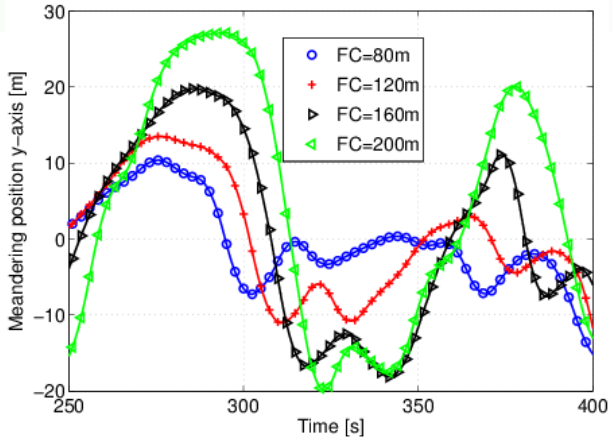


FC=160m (4D)



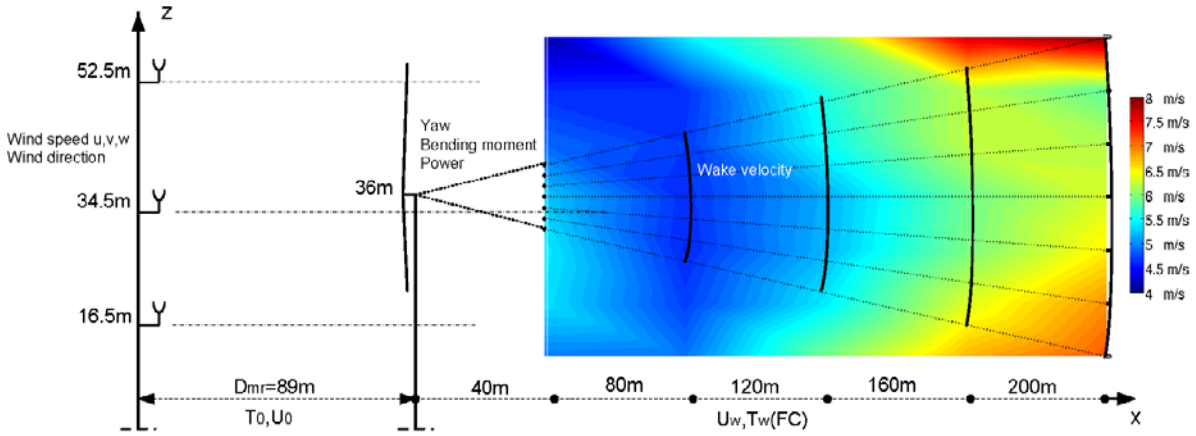
FC=200m (5D)





4 – Modeled wake meandering (DWM model)

- 1- Main flow direction: constant Taylor advection velocity UT



Guess: N.O. Jensen

$$U_w = \sqrt{1 - CT} \cdot U_0$$

Tower bending moment

$$t_0 = \frac{D_{mr}}{U_0} \qquad t_w(FC) = \frac{FC}{U_w} \qquad \tilde{t}(FC) = t_0 + t_w(FC)$$

- 2- Lateral displacement: large scale lateral turbulent velocities at specific position and time instant

$$y(FC, \tilde{t}) = v_c(\tilde{t}) \cdot \tilde{t}(FC) + h_{yaw}(FC, \tilde{t})$$

$$z(FC, \tilde{t}) = w_c(\tilde{t}) \cdot \tilde{t}(FC) + \cancel{h_{tilt}(FC, \tilde{t})}$$

Scanning head aligned horizontally with ground

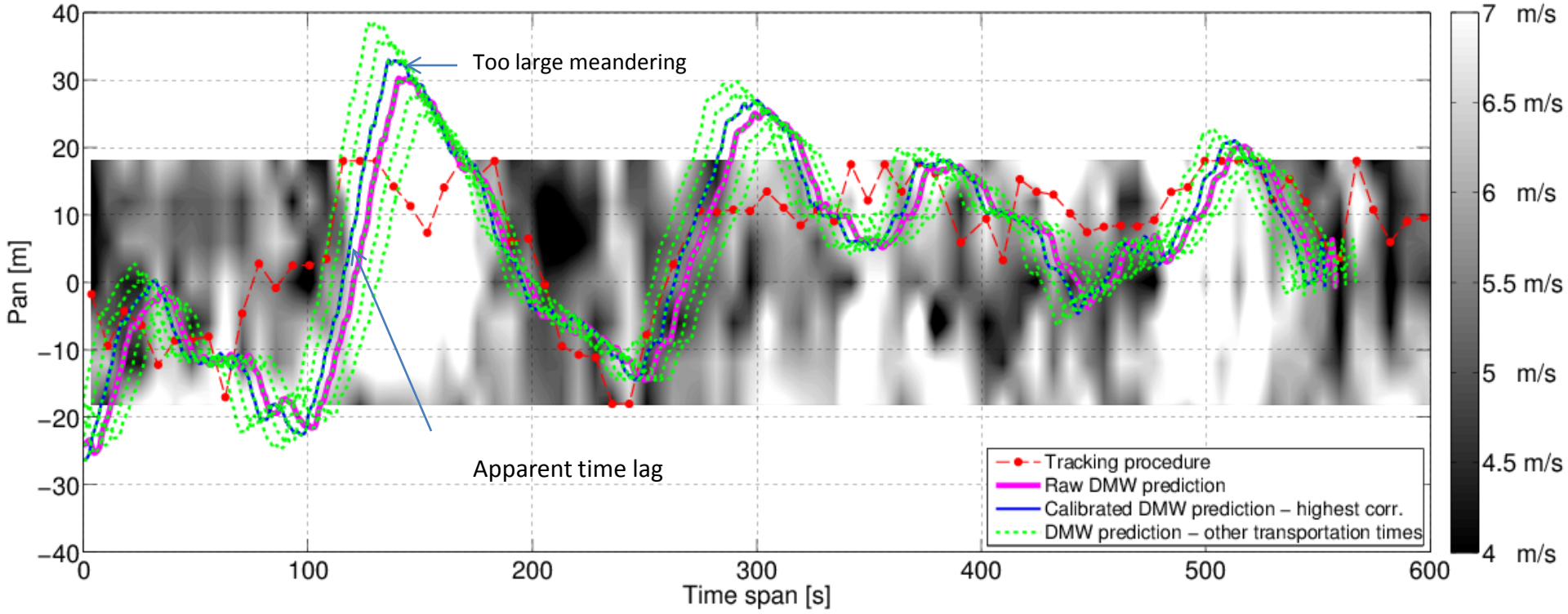
$v_c(\tilde{t})$: large scale lateral velocities

$h_{yaw}(FC, \tilde{t})$: yaw displacement contribution

$\tilde{t}$: elapsed time for wake release to reach FC

4 – Analysis - Dynamic Wake Meandering

Prediction from model against measured meandering at FC=120m (3D)



→ Mean advection time difference: cross correlation analysis → 5.5s

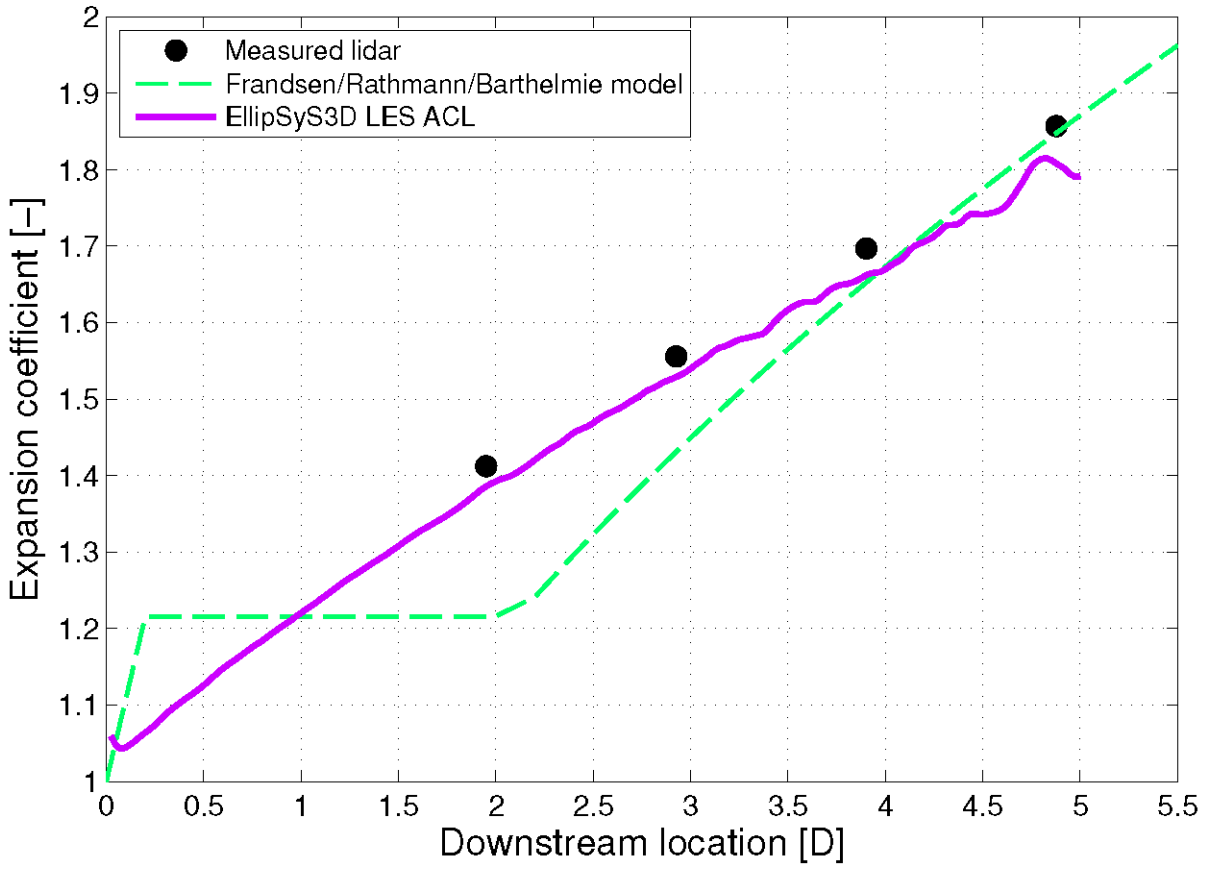
(U0=8.1 m/s)	U_w	t	t_{adv}
DMW Raw	3.4m/s (N.O. Jensen)	46s	35s
DMW Calibrated	4.06m/s	40.5s	29.5s

→ N.O. Jensen model underestimate the wake advection velocity in this case

4 – Single wake expansion

10 min average expansion coefficient in fixed frame of reference

E [-] = Wake width [m] / D0 [m]



- Good agreement with EllipSyS3D
- Good agreement with engineering model in far wake

O. Rathmann, R. Barthelmie, and S. Frandsen. Turbine Wake Model for Wind Resource Software. *EWEC 2006 Wind Energy Conference and Exhibition, Scientific Proceedings*, 2006.

5 – Conclusion and future work

Achievements:

- DWM prediction are robust
- Uncertainties in advection velocity using N.O. Jensen assumptions
- Good agreement between measured and simulated expansion in fixed frame of reference

Current / future work:

- Direct estimation of wake advection velocity from pulsed lidar measurements
- Empirical formulation of advection velocity as function of wake deficit
- New single wake expansion engineering model

Thank you for your attention

Questions ? Suggestions ?

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